Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Optimization of Electronically Scanned Conformal Antenna Array Synthesis Using Artificial Neural Network Algorithm

HAMDI Bilel(1,2) **AGUILI Taoufik(1)**

(1)SYS'COM Laboratory, El Manar University -National Engineering school of Tunis - Tunisia

(2)Laplace Laboratory, ENSEEIHT, 2 rue Camichel, Toulouse Cedex 4, 31071, France

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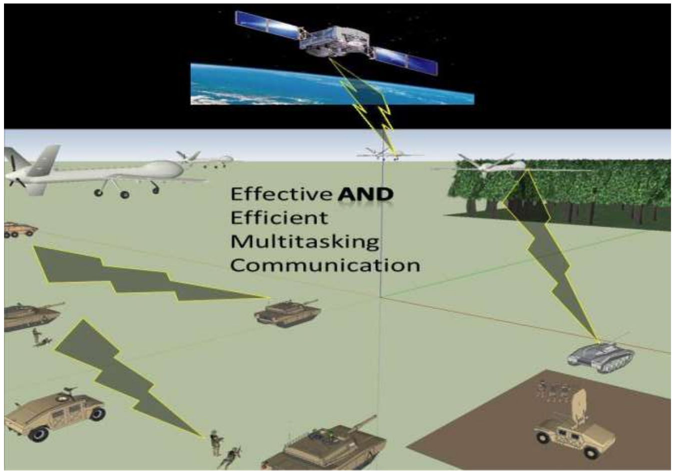
Abstract

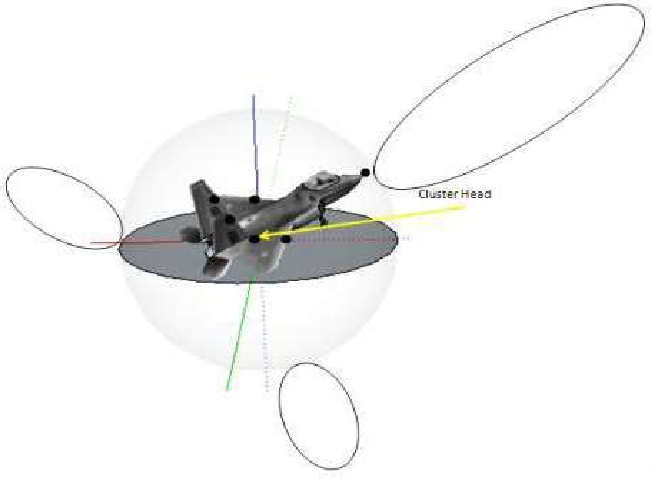
Studying of mechanical steerable antennas has been considered the subject of feature research. In order to reduce the cost of the mechanical system and to grow up the steering capabilities of the radar, we suggest replacing any mechanical antenna components with an electronically controlled 3D or conformal antennas arrays. 3D antenna arrays can be easily produced with existing manufacturing technologies and offer a considerable advantages in terms of 3-D steerable radiation beam, size, directivity, HPBW and SLL reduction. In this paper, we have developed the neural networks method based beamforming that will be applied to the array pattern synthesis for three-dimensional (3D) conformal antenna arrays. This approach permits to model and optimize the antenna arrays system, by acting on many parameters of the array and taking into account predetermined general criteria.

The goal is then to build a feed-forward neural network with supervised learning that approximates the following array pattern’s function. It explains how to introduce the basic principles of artificial neural network (ANN), some fundamental networks are examined in detail for their ability to solve simple pattern synthesis problem in conformal antenna arrays. This fact increases the complexity of the problem under consideration and fitting the neural network model, such as training function, architecture and parameter that would improve and result more accuracy about input-output relations. Then, the used neural technique proved its effectiveness in improving performance using the known conformal isotropic antenna arrays.

Regular 3D and Conformal Phased Array Antennas

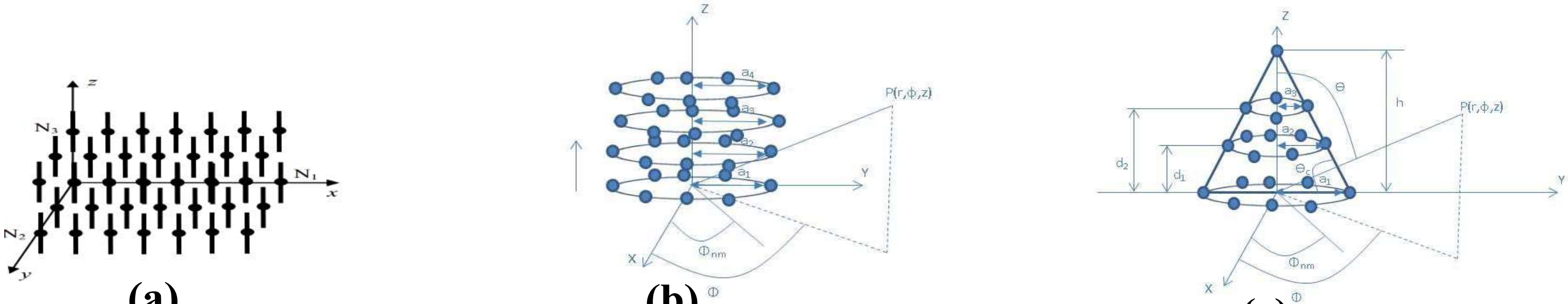


Distributed beamforming in the battlefield



Randomly distributed antennas

Alaska Radar



(a)

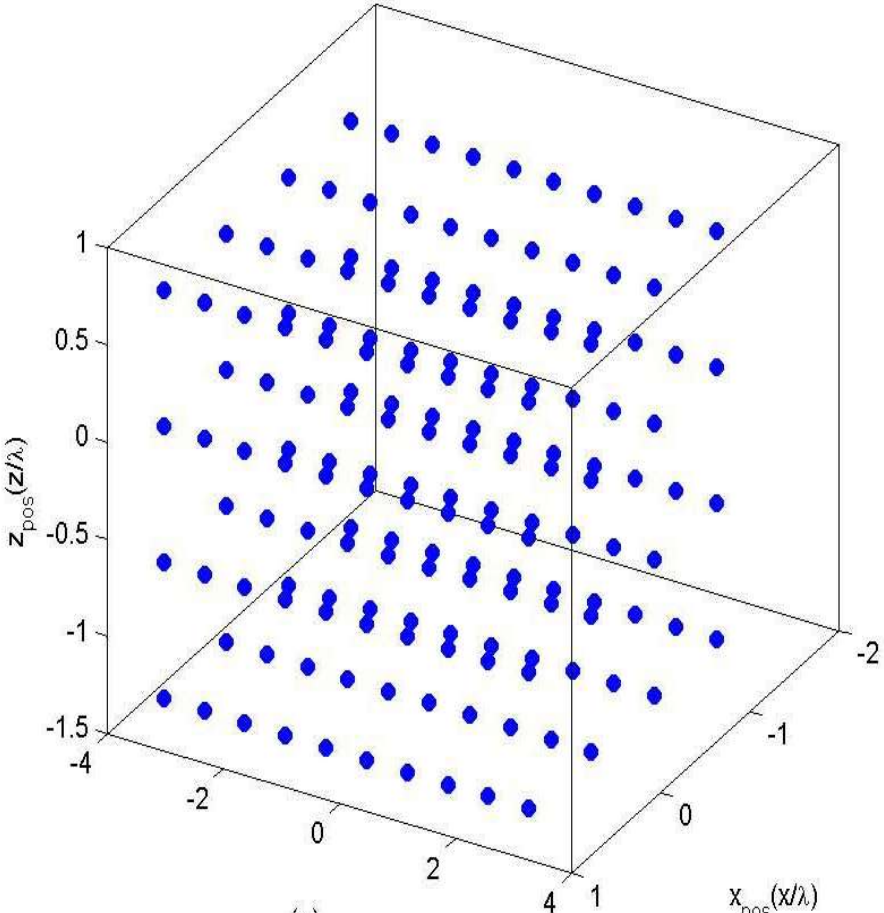
(b)

(c)

Regular 3D and conformal antenna arrays topologies (a) Cubic array (b) Cylindrical array (c) Conical array

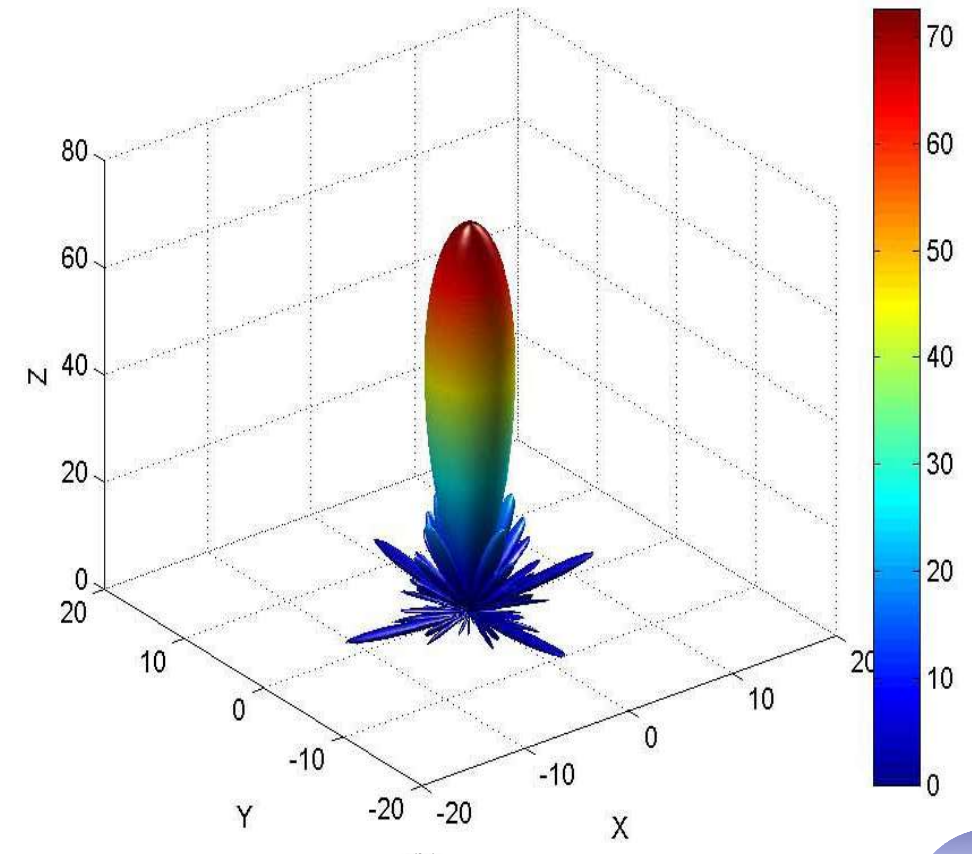
Geometries and Array Factor Formulation

(3-D)Three – dimensional array antennas : elements arranged in a cubic grid

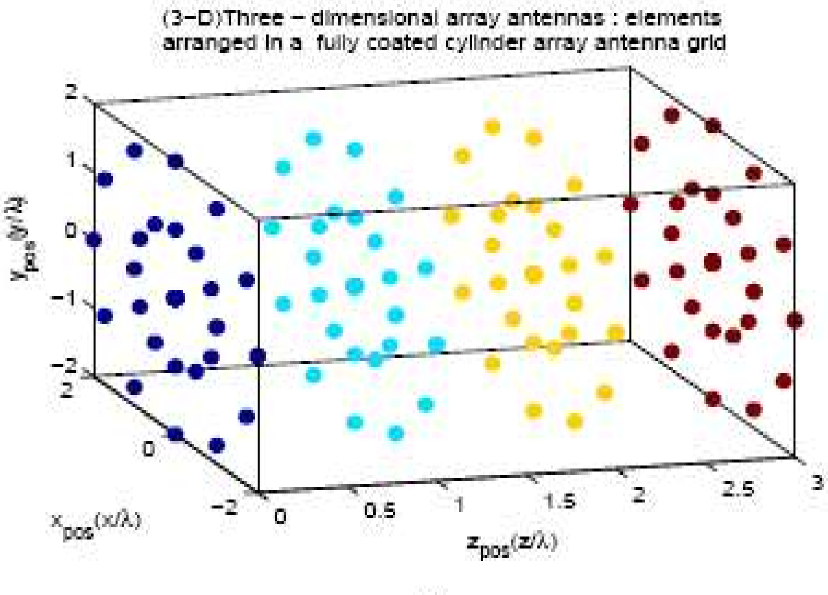


(a)

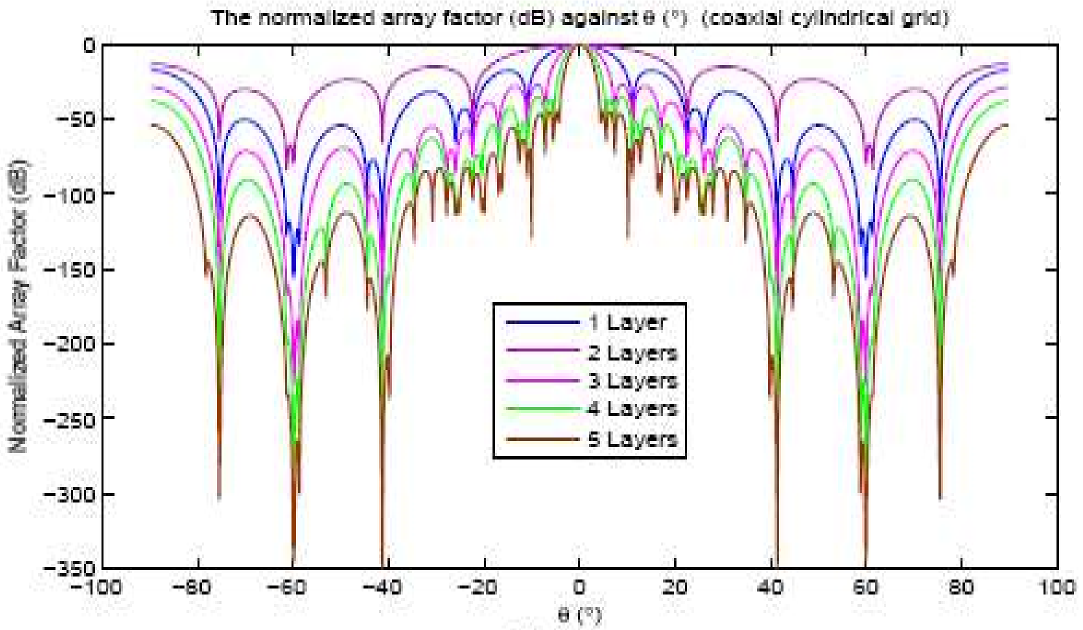
3-D Radiation pattern for a three-dimensional array antennas arranged in a cubic grid using: $N_x = N_z = 4$ elements, $N_y = 10$ elements, $d_x = d_y = d_z = 0.7\ \lambda$



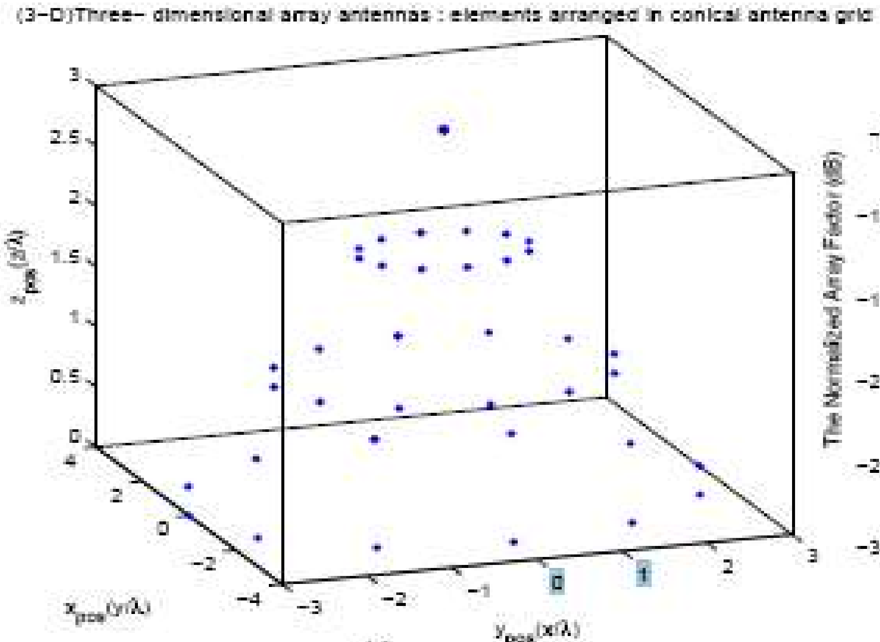
(b)


(3−D)Three − dimensional array antennas : elements
arranged in a fully coated cylinder array antenna grid
$y_{pos}(y/\lambda)$
$x_{pos}(x/\lambda)$
$z_{pos}(z/\lambda)$
2
1
0
−1
−2
2
0
−2
0
0.5
1
1.5
2
2.5
3

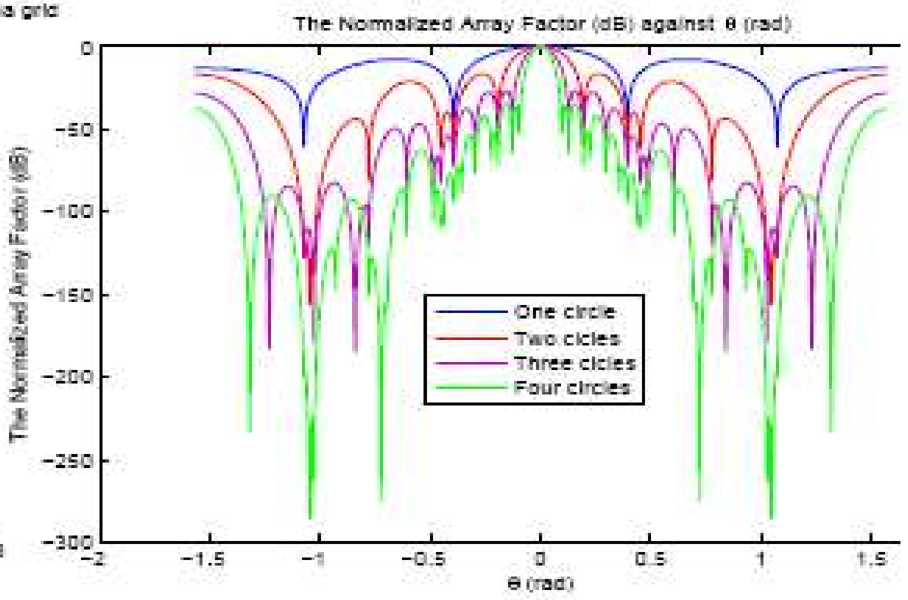
(a)


The normalized array factor (dB) against θ (°) (coaxial cylindrical grid)
Normalized Array Factor (dB)
θ (°)
1 Layer
2 Layers
3 Layers
4 Layers
5 Layers
0
−50
−100
−150
−200
−250
−300
−350
−100
−80
−60
−40
−20
0
20
40
60
80
100

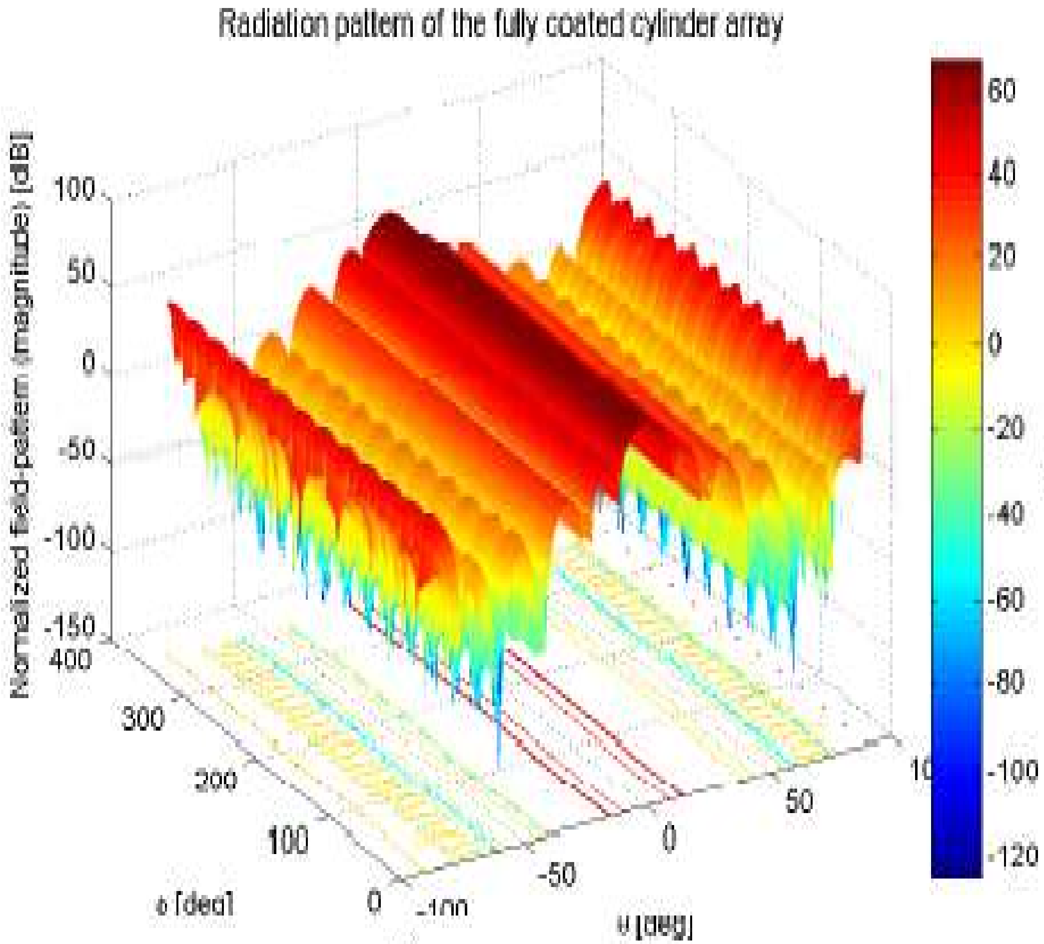
(b)


(3−D)Three− dimensional array antennas : elements arranged in conical antenna grid
$z_{pos}(z/\lambda)$
$x_{pos}(y/\lambda)$
$y_{pos}(x/\lambda)$
3
2.5
2
1.5
1
0.5
0
4
2
0
−2
−4
−3
−2
−1
0
1
2
3

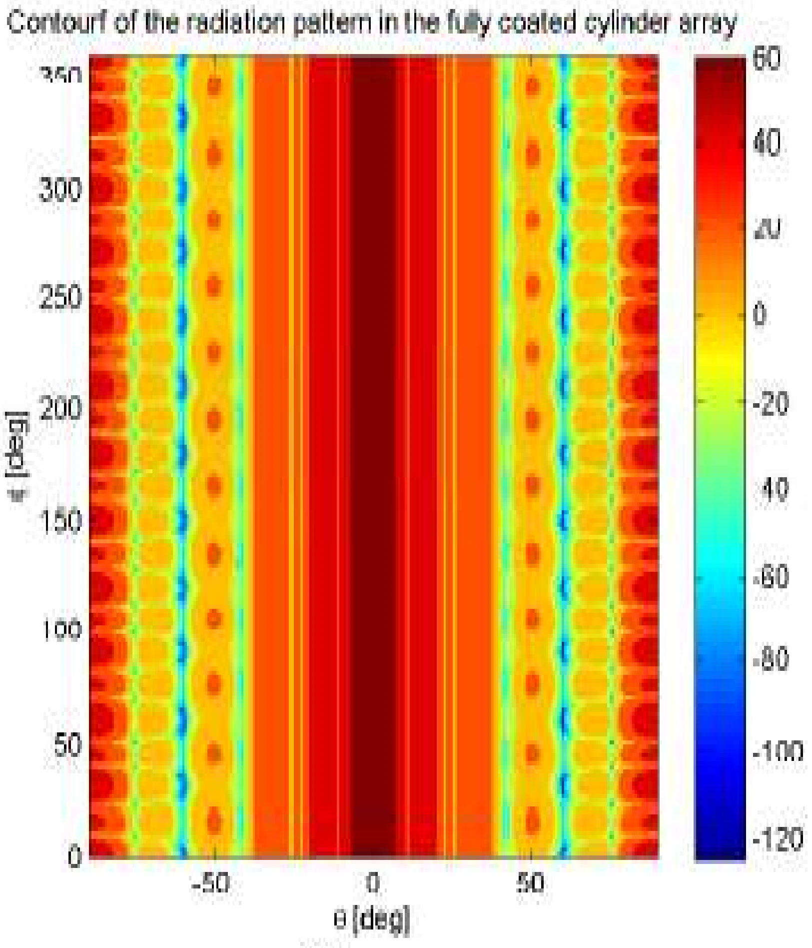
(a)


The Normalized Array Factor (dB) against θ (rad)
The Normalized Array Factor (dB)
θ (rad)
One circle
Two circles
Three circles
Four circles
0
−50
−100
−150
−200
−250
−300
−2
−1.5
−1
−0.5
0
0.5
1
1.5

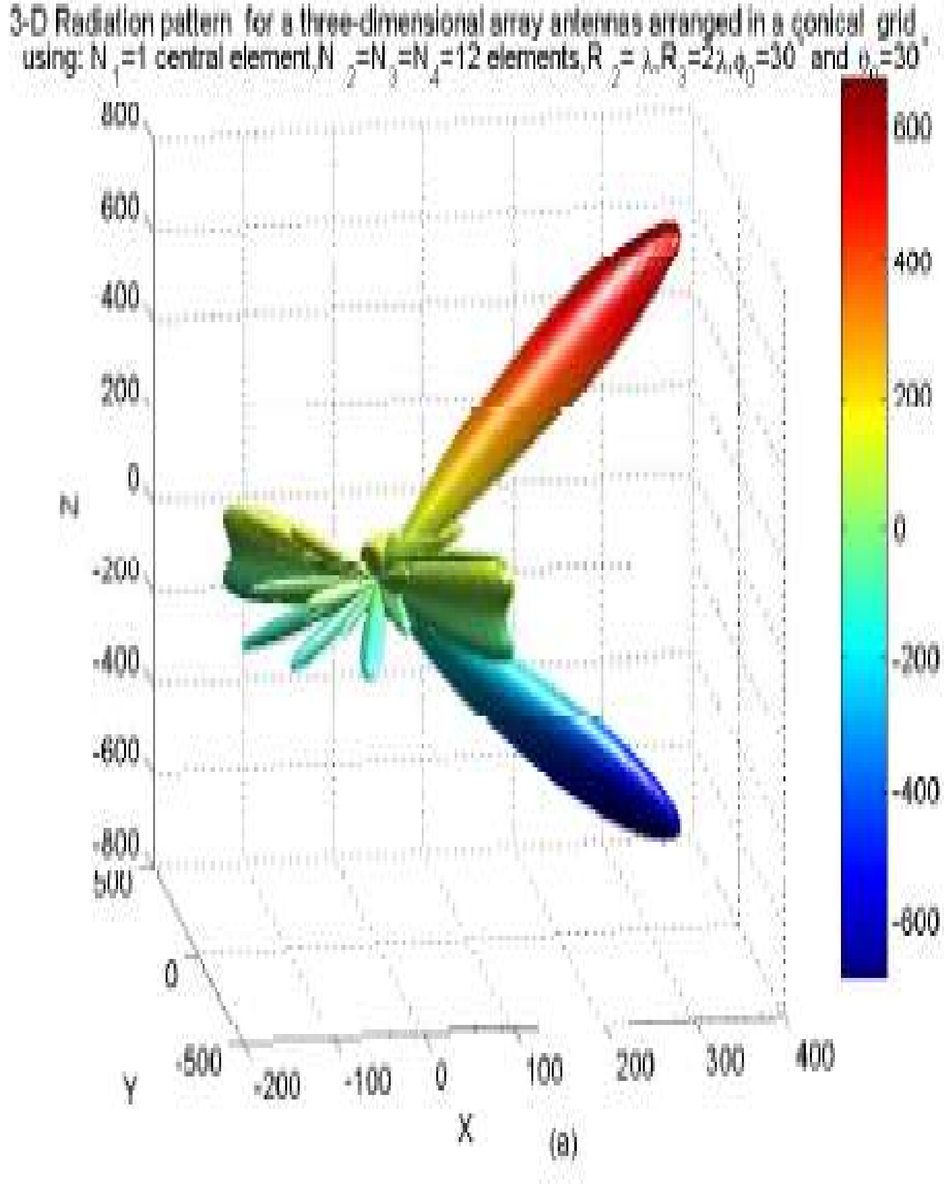
(b)


Radiation pattern of the fully coated cylinder array

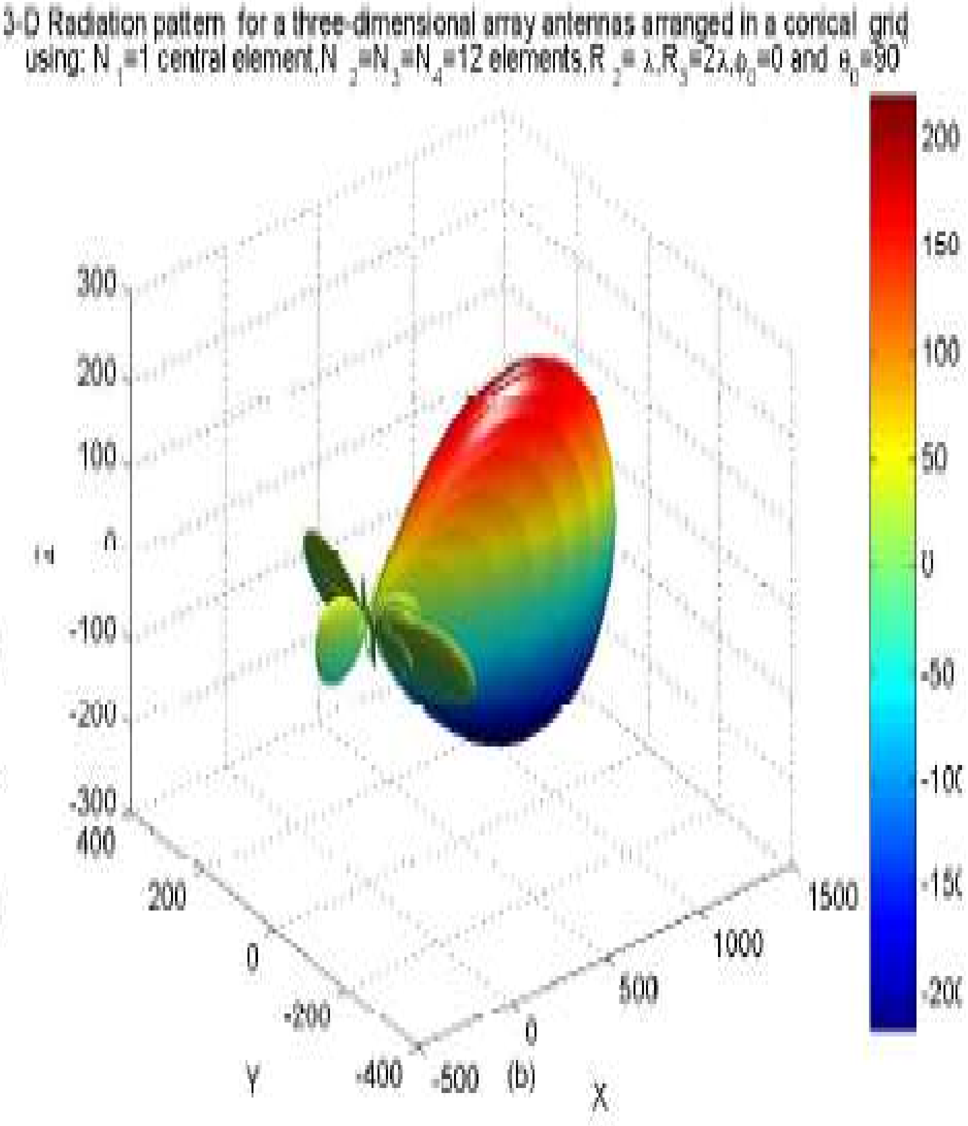
(a)


Contourf of the radiation pattern in the fully coated cylinder array

(b)

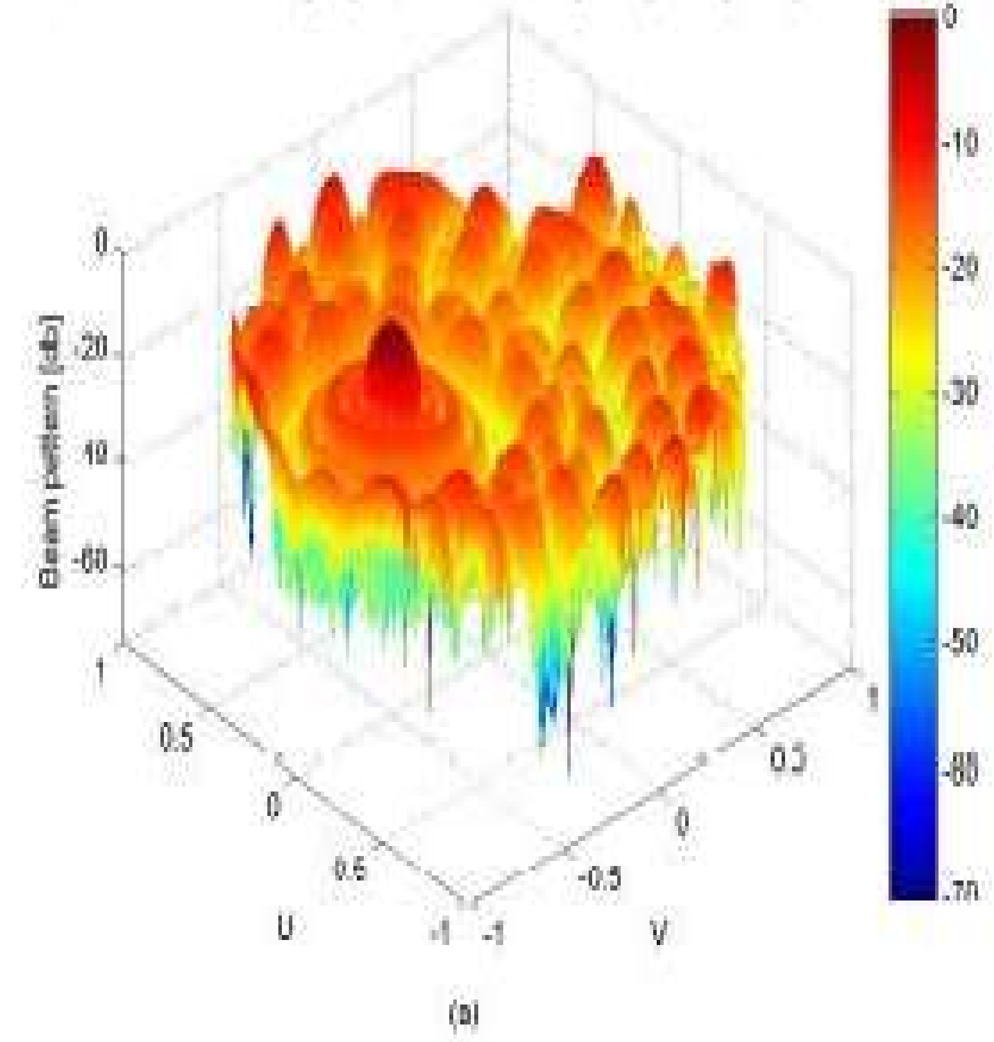

3-D Radiation pattern for a three-dimensional array antennas arranged in a conical grid
using: N 1=1 central element,N 2=N 3=N 4=12 elements,R 2= λ,R 3=2λ,φ0=30 and θ0=30
800
600
400
200
0
-200
-400
-600
-800
N
500
0
-500
Y
-200
-100
0
100
200
300
400
X
600
400
200
0
-200
-400
-600

(a)


3-D Radiation pattern for a three-dimensional array antennas arranged in a conical grid
using: N 1=1 central element,N 2=N 3=N 4=12 elements,R 2= λ,R 3=2λ,φ0=0 and θ0=90
300
200
100
0
-100
-200
-300
400
200
0
-200
-400
Y
-500
0
500
1000
1500
X
200
150
100
50
0
-50
-100
-150
-200

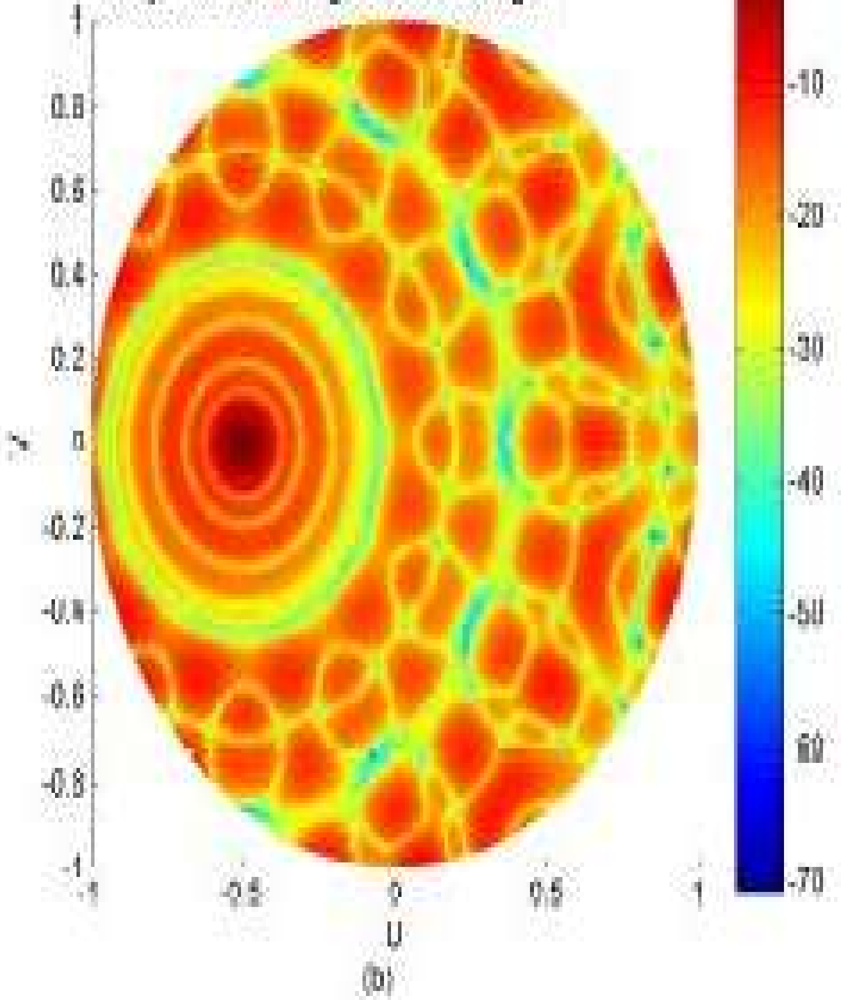
(b)

The Beam pattern in (db) for a three-dimensional array antennas arranged in a conical grid using: $N_1=1$ central element $N_2=N_3=N_4=12$ elements $R_2=\lambda, R_3=2\lambda, R_4=3\lambda, \theta_0=30^\circ$ and $\phi_0=180^\circ$



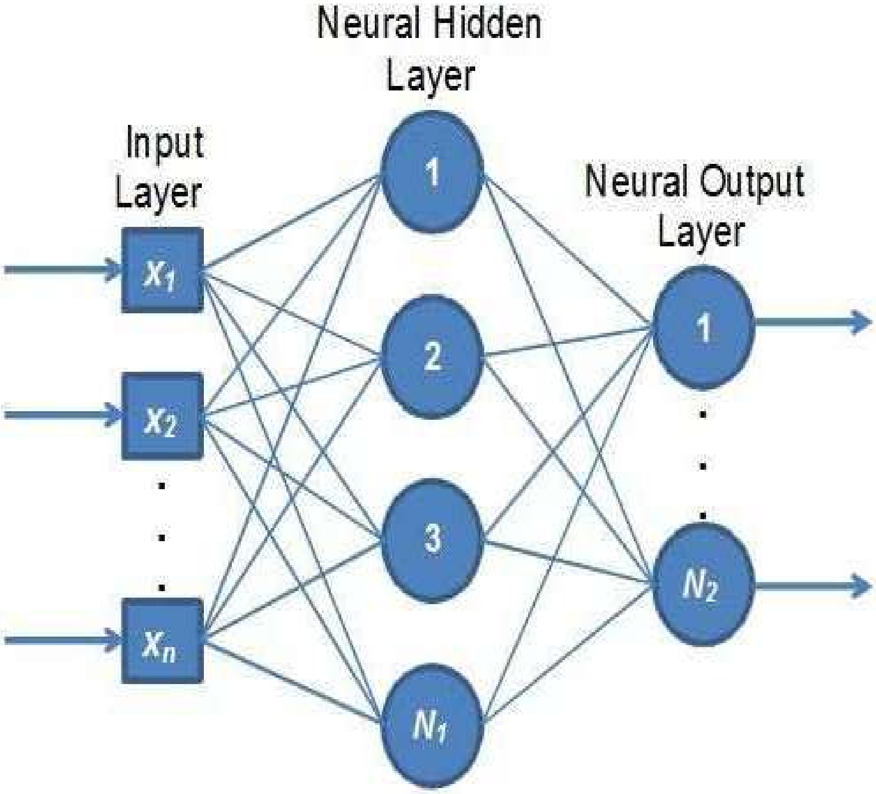
(a)

Contourf of the beam pattern in (db) for a three-dimensional array antennas arranged in a conical grid

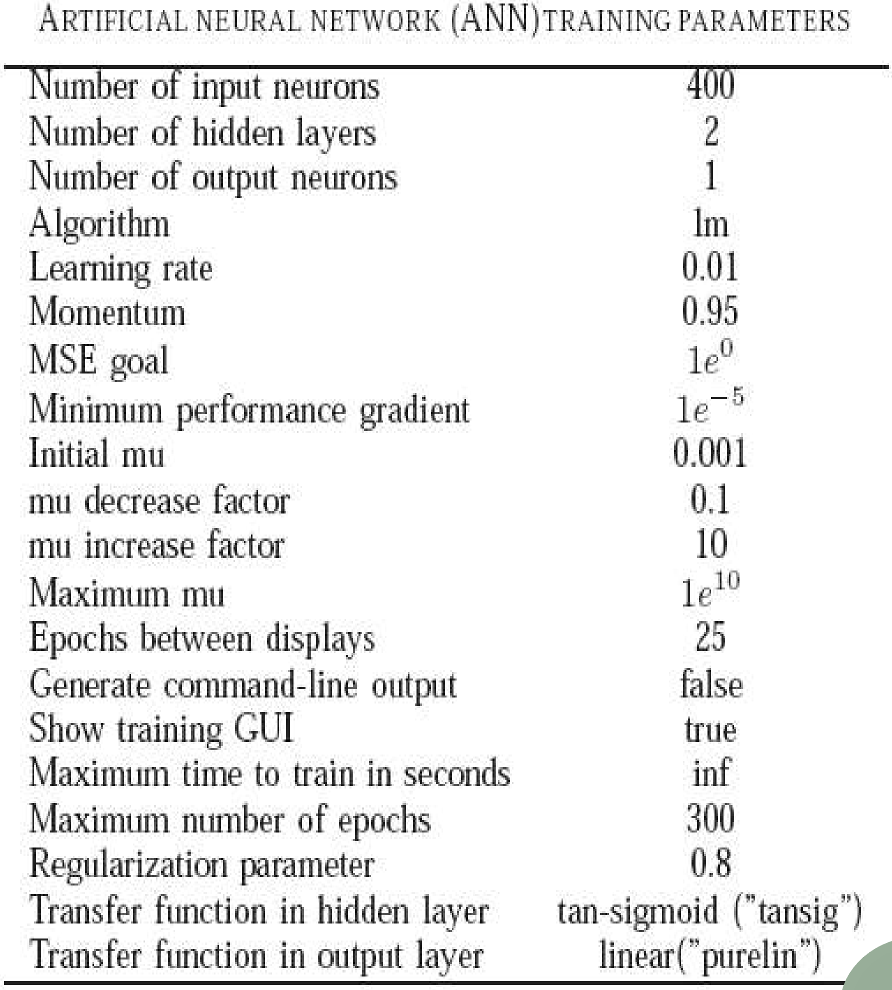


(b)

Artificial Neural Networks (ANN) Principle

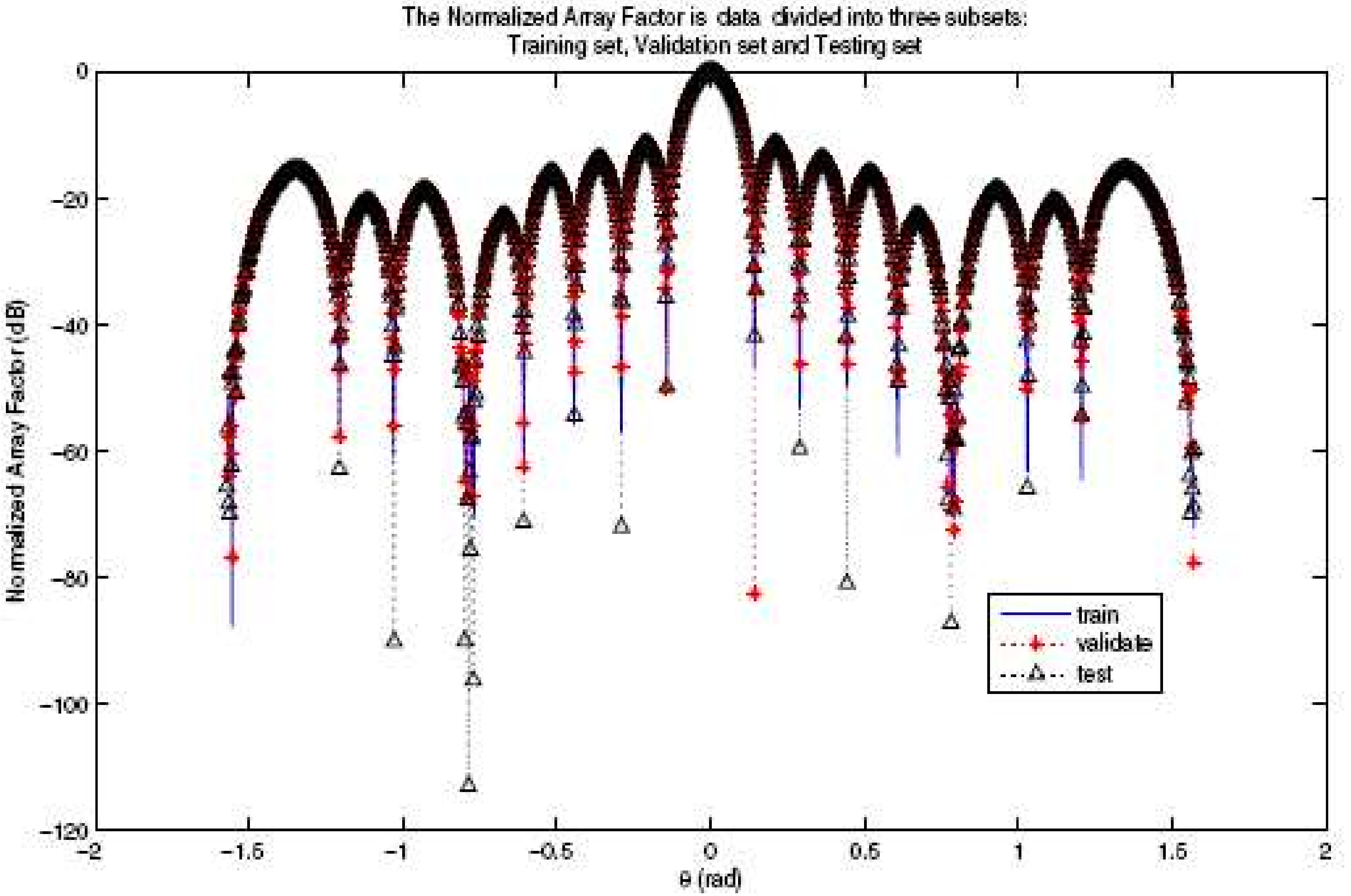


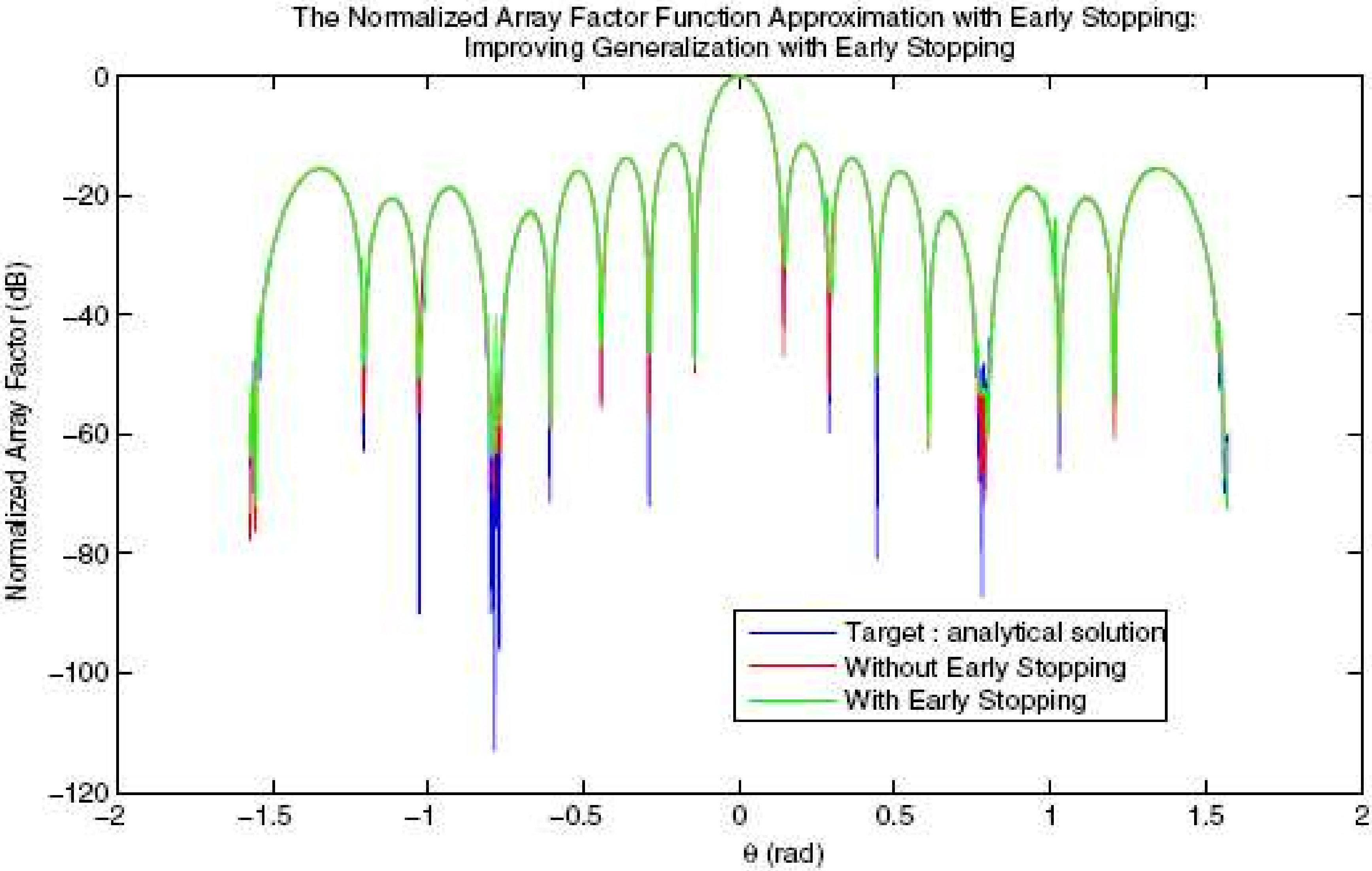
ANN architecture

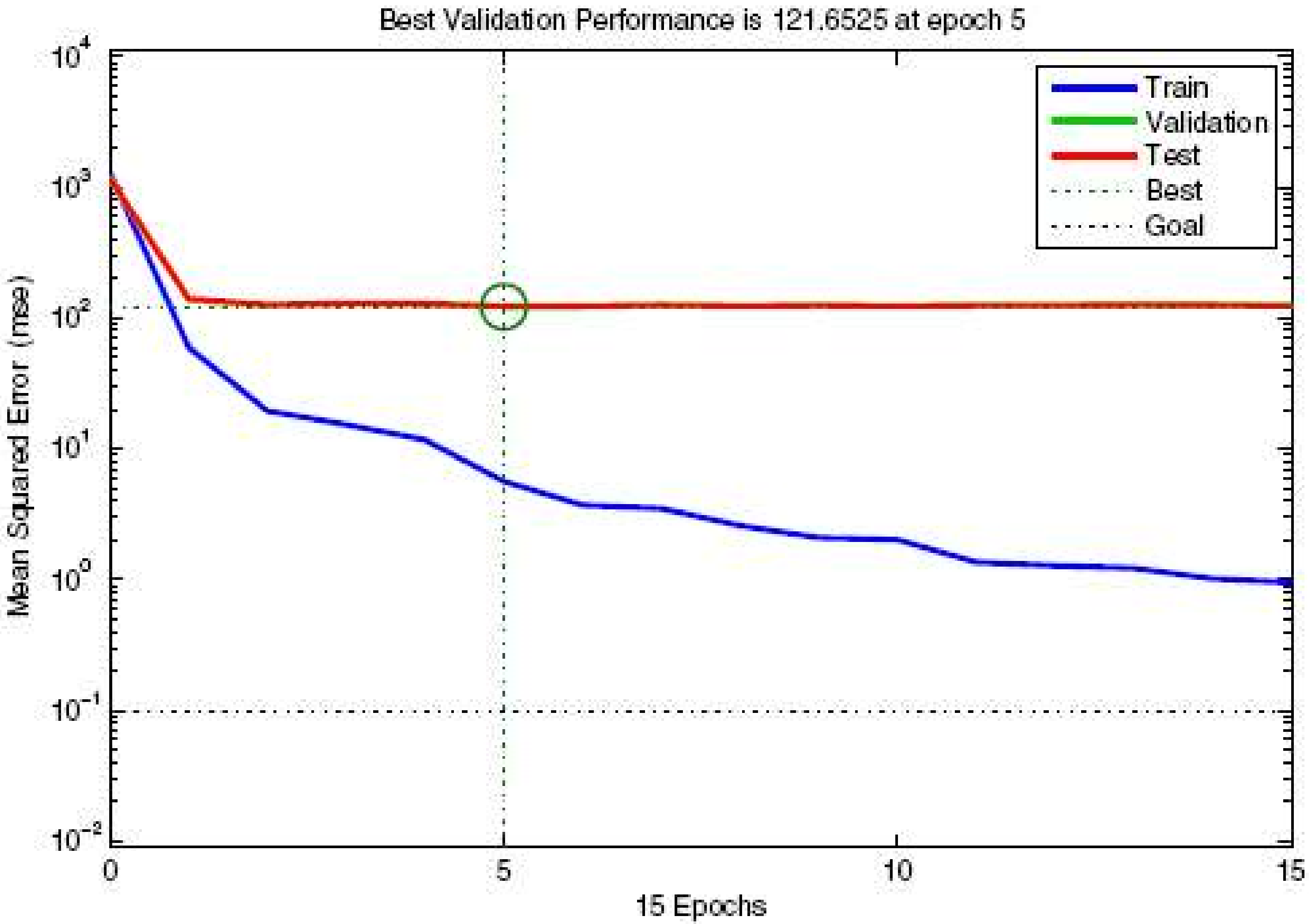


ARTIFICIAL NEURAL NETWORK (ANN) TRAINING PARAMETERS

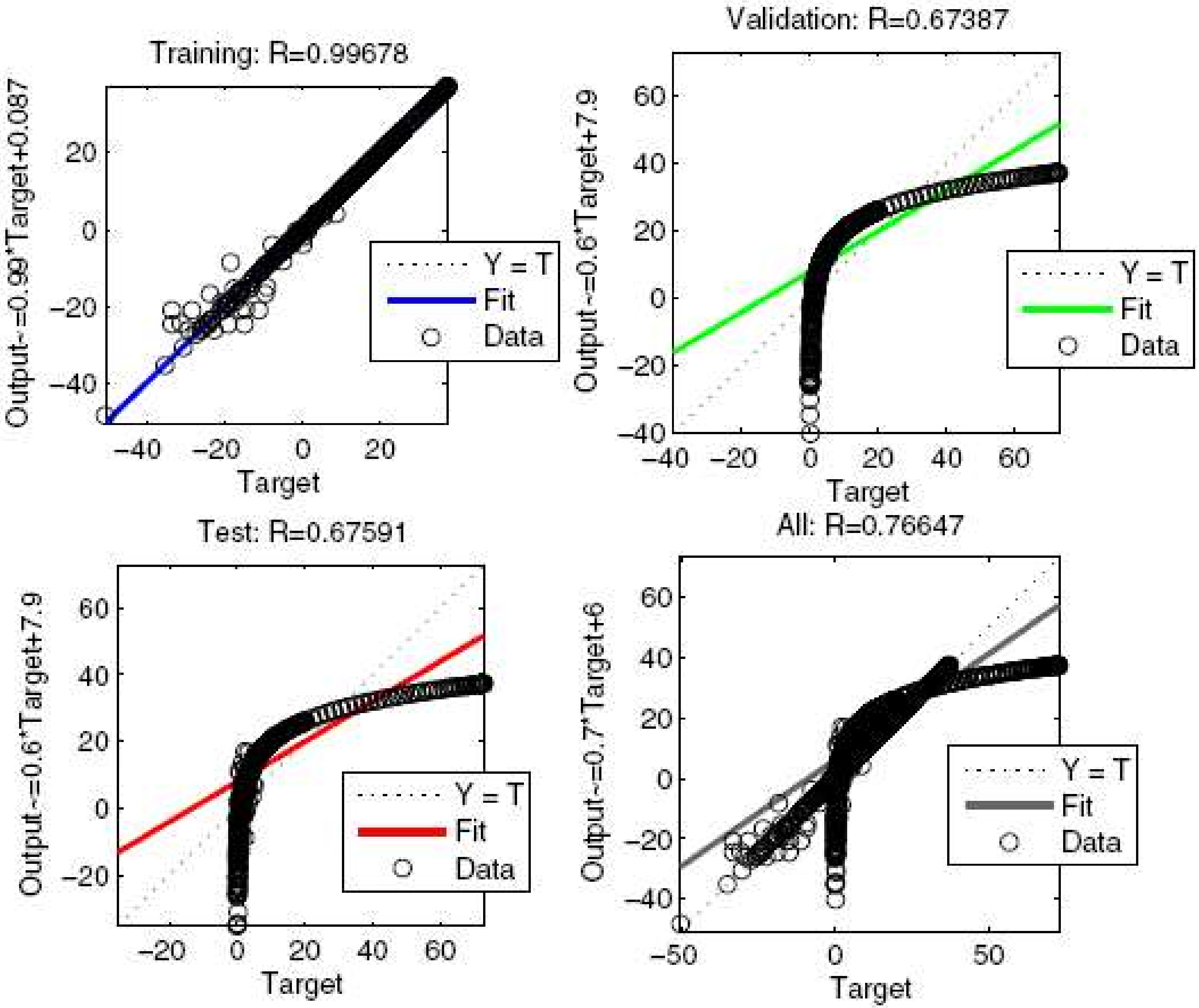
Number of input neurons	400
Number of hidden layers	2
Number of output neurons	1
Algorithm	lm
Learning rate	0.01
Momentum	0.95
MSE goal	$1e^{0}$
Minimum performance gradient	$1e^{-5}$
Initial mu	0.001
mu decrease factor	0.1
mu increase factor	10
Maximum mu	$1e^{10}$
Epochs between displays	25
Generate command-line output	false
Show training GUI	true
Maximum time to train in seconds	inf
Maximum number of epochs	300
Regularization parameter	0.8
Transfer function in hidden layer	tan-sigmoid ("tansig")
Transfer function in output layer	linear("purelin")


The Normalized Array Factor is data divided into three subsets:
Training set, Validation set and Testing set
Normalized Array Factor (dB)
0
-20
-40
-60
-80
-100
-120
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
θ (rad)
train
validate
test


The Normalized Array Factor Function Approximation with Early Stopping:
Improving Generalization with Early Stopping



Mean squared error (mse)



Regression plot

Conclusion

In this paper, we considered the steering array pattern synthesis of regular 3D and conformal phased arrays antenna using artificial neural network(ANN) adaptive beamforming algorithm. Several neural-network architectures has been simulated and tested with their effectiveness for array-pattern synthesis which has been compared. The results prove that MLP neural networks training model present a good performances matching to predict the desired radiation. The proposed structures are used in many applications that require coverage over the full 360◦ of azimuth with little variation of Side Lobe Level (SLL) or bandwidths. This work is necessary starting point for future investigation of neural network solution for irregular antenna array synthesis.

References

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Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Floquet Modal Analysis to Modelize and Study 1D and 2-D Planar Almost Periodic Structures in Finite and Infinite Extent with Coupled Motifs

HAMDI Bilel(1,2) **AGUILI Taoufik**(1) **BAUDRAND Henri**(2)

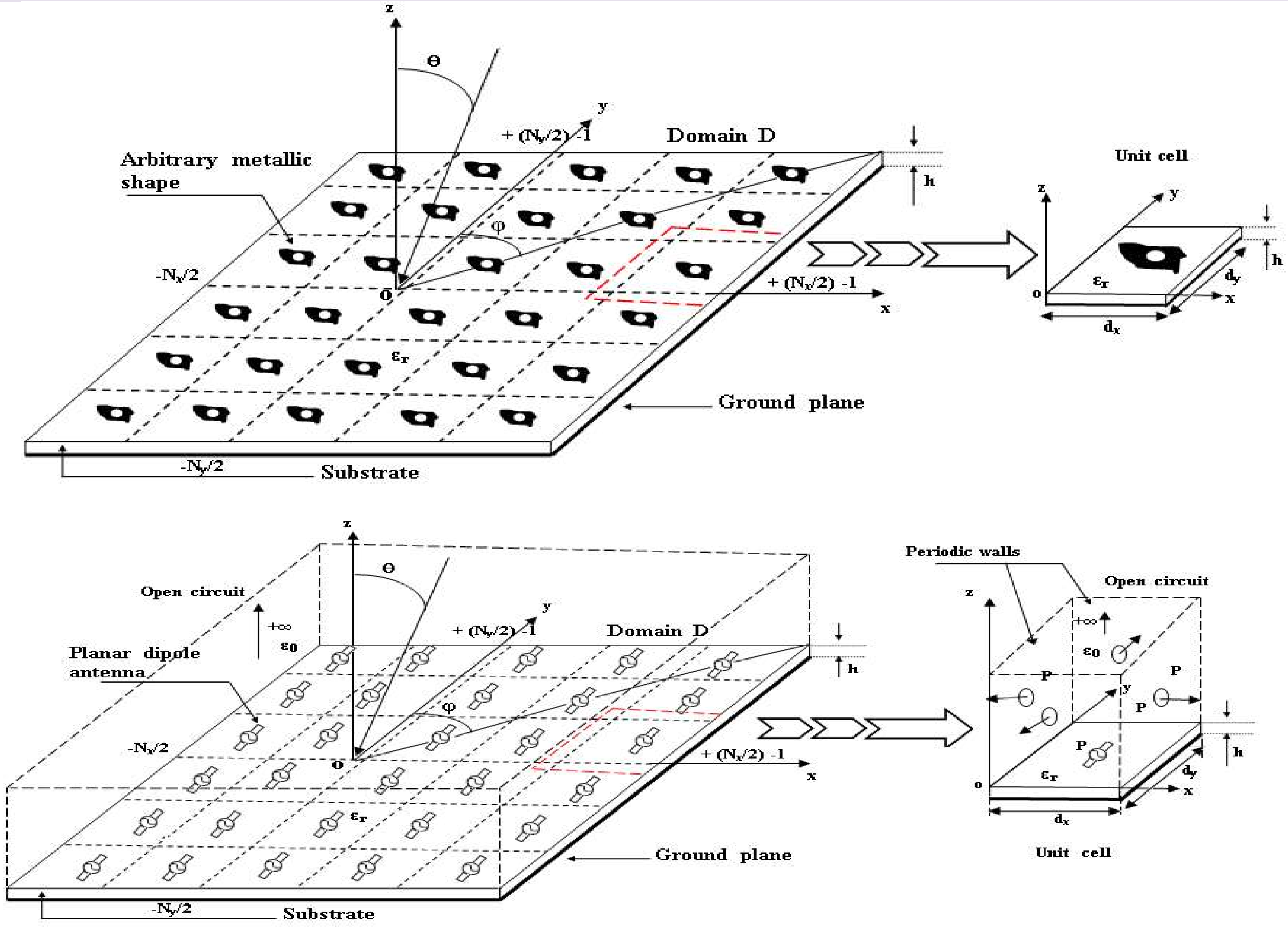
(1)SYS'COM Laboratory, El Manar University -National Engineering school of Tunis - Tunisia

(2)Laplace Laboratory, ENSEEIHT, 2 rue Camichel, Toulouse Cedex 4, 31071, France

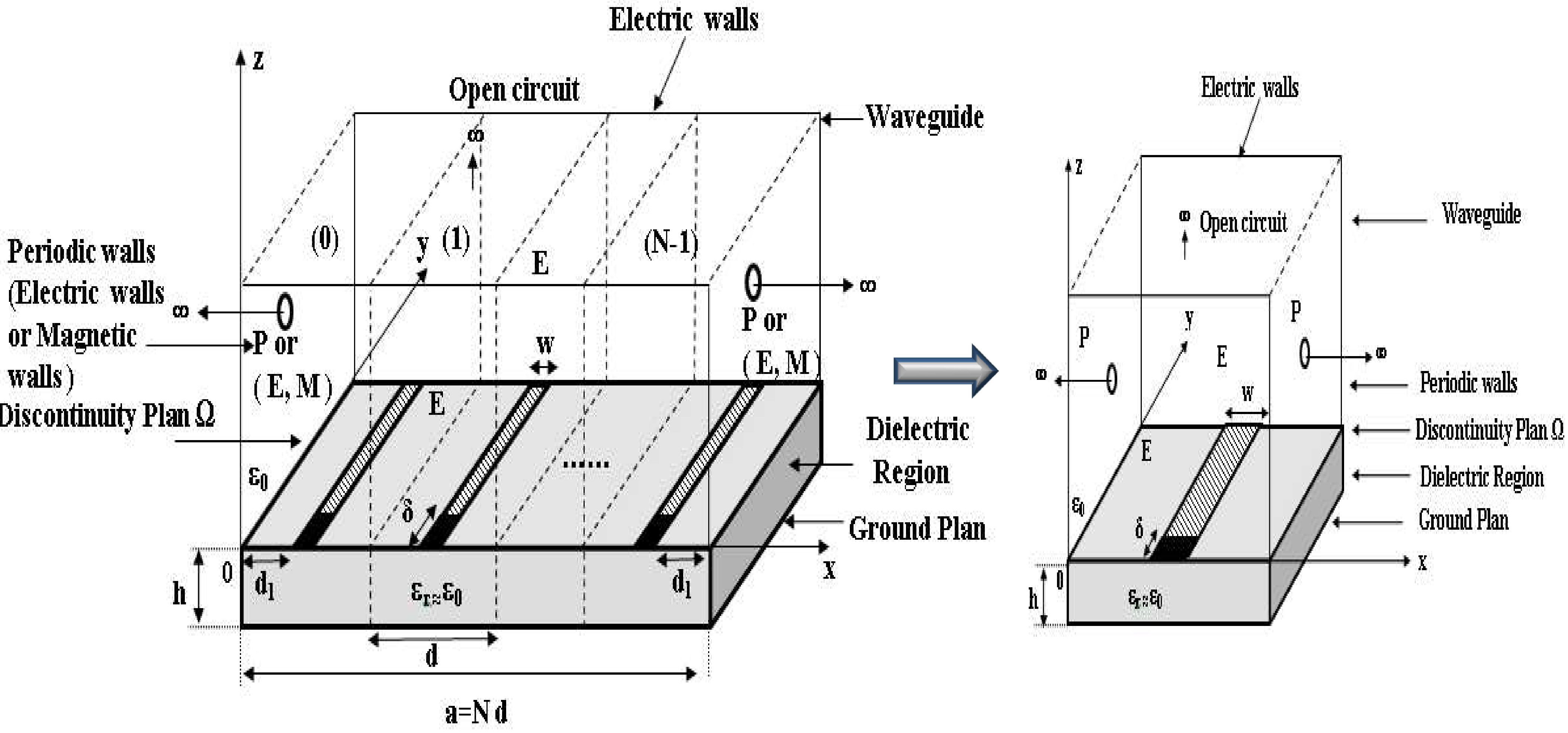
Abstract

Studying of mutual coupling parameters between the antenna elements in an array environment has been considered as the subject of feature research. That is why, in this paper, we present a new Floquet modal analysis procedure for analyzing almost periodic structures. Accurate evaluation of the mutual coupling could be achieved by this analysis. It is shown how Floquet analysis can be exploited to study a finite array with arbitrary amplitude and linear phase distribution in both x-y directions including mutual coupling effects. Two different calculation methods of coupling coefficients between the array elements are presented, in spectral and spatial domains, to solve the suggested problem. For modeling the given structures, the moment method combined with Generalized Equivalent Circuit (MoM-GEC) is proposed. High gain in the running time and memory used is given using Floquet analysis. To validate this work, several examples are shown .

Proposed structures

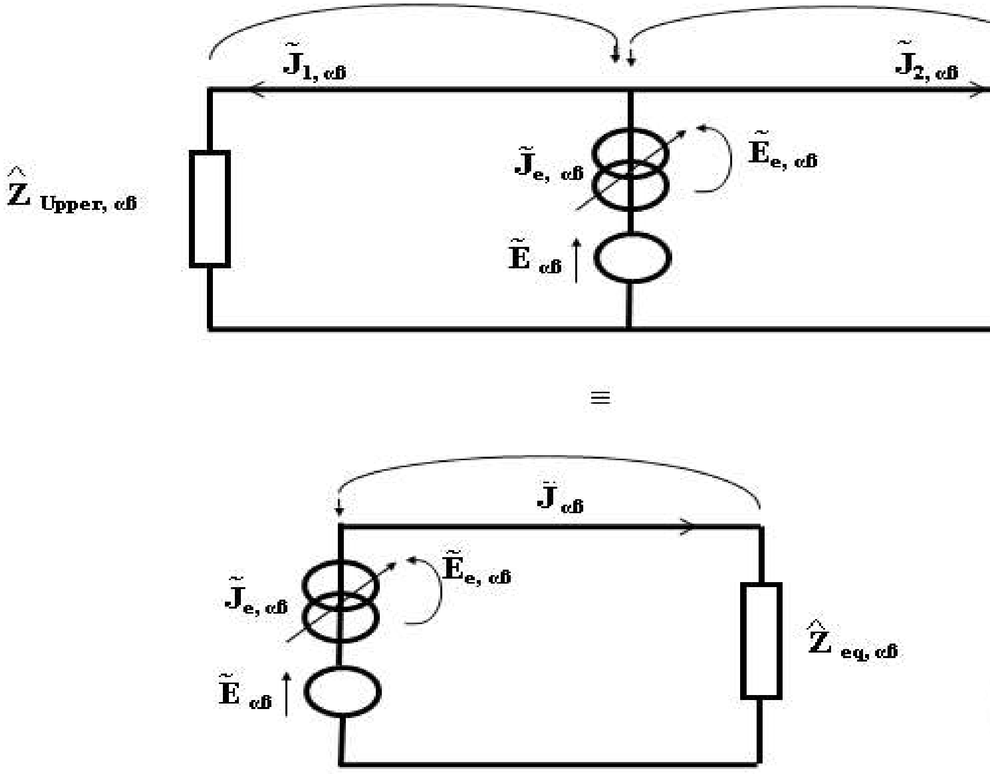


2-D Almost Periodic cells with arbitrary planar metallic shape (arbitrary motifs)



A section of 1-D almost periodic phased array micro-strip lines

Proposed structures



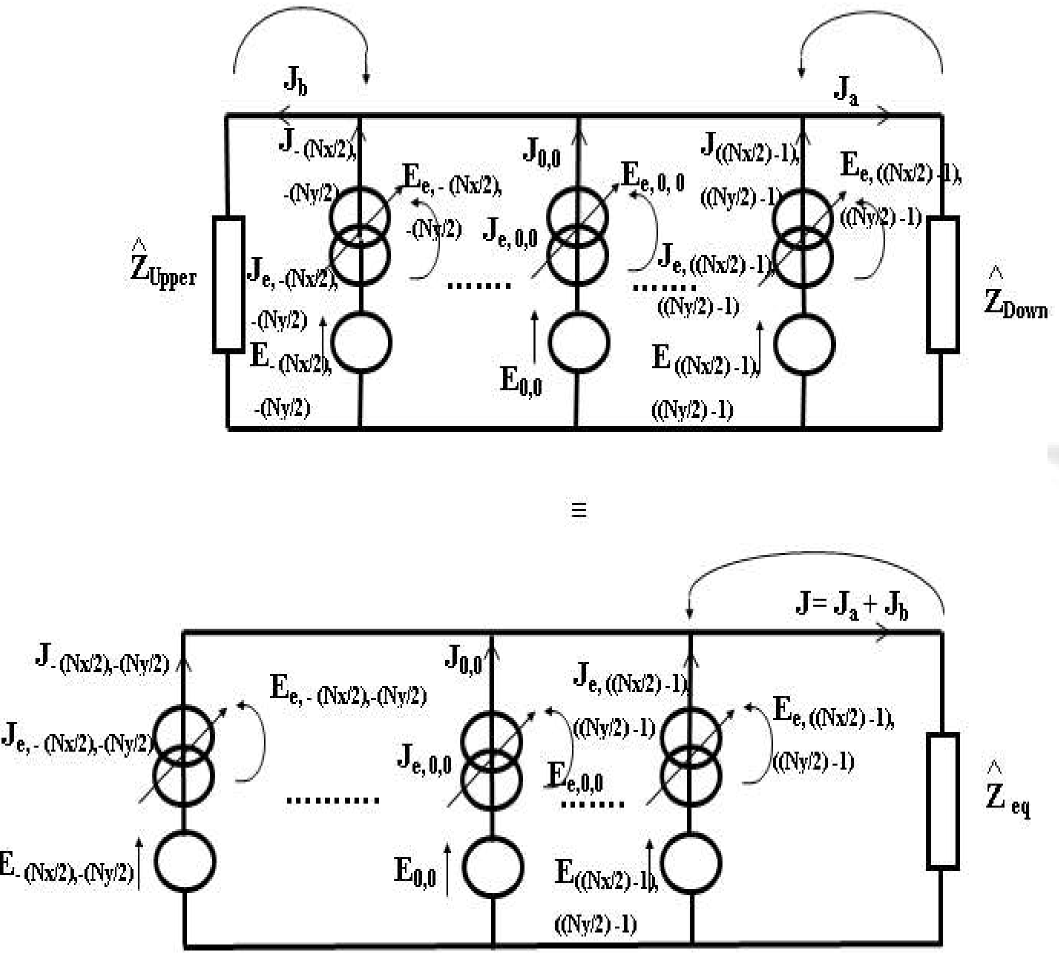
Equivalent circuit for the global structure

$$\tilde{Z}_{in,\alpha\beta} = \left({}^{t}[\tilde{A}_{\alpha\beta}]([\hat{Z}^{down}_{pq,ht,\alpha\beta}]^{-1} + [\hat{Z}^{upper}_{pq,ht,\alpha\beta}]^{-1})[\tilde{A}_{\alpha\beta}]\right)^{-1}$$

Floquet modal input impedance

$$\begin{cases} \tilde{J}_{\alpha\beta} = \tilde{J}_{e,\alpha\beta} \\ \tilde{E}_{e,\alpha\beta} = -\tilde{E}_{\alpha\beta} + \hat{Z}_{\alpha\beta}\tilde{J}_{e,\alpha\beta} \end{cases}$$

?? Boundaries conditions in term current and tension (kirchhoff laws) : basic element



Equivalent circuit for the global structure

$$[Z_{i,s}] = \left[\frac{V_{i,i}}{I_{s,s}}\right] = \left({}^{t}[A]([\hat{Z}^{down}_{pq,ht}]^{-1} + [\hat{Z}^{upper}_{pq,ht}]^{-1})[A]\right)^{-1}$$

Impedance matrix interaction

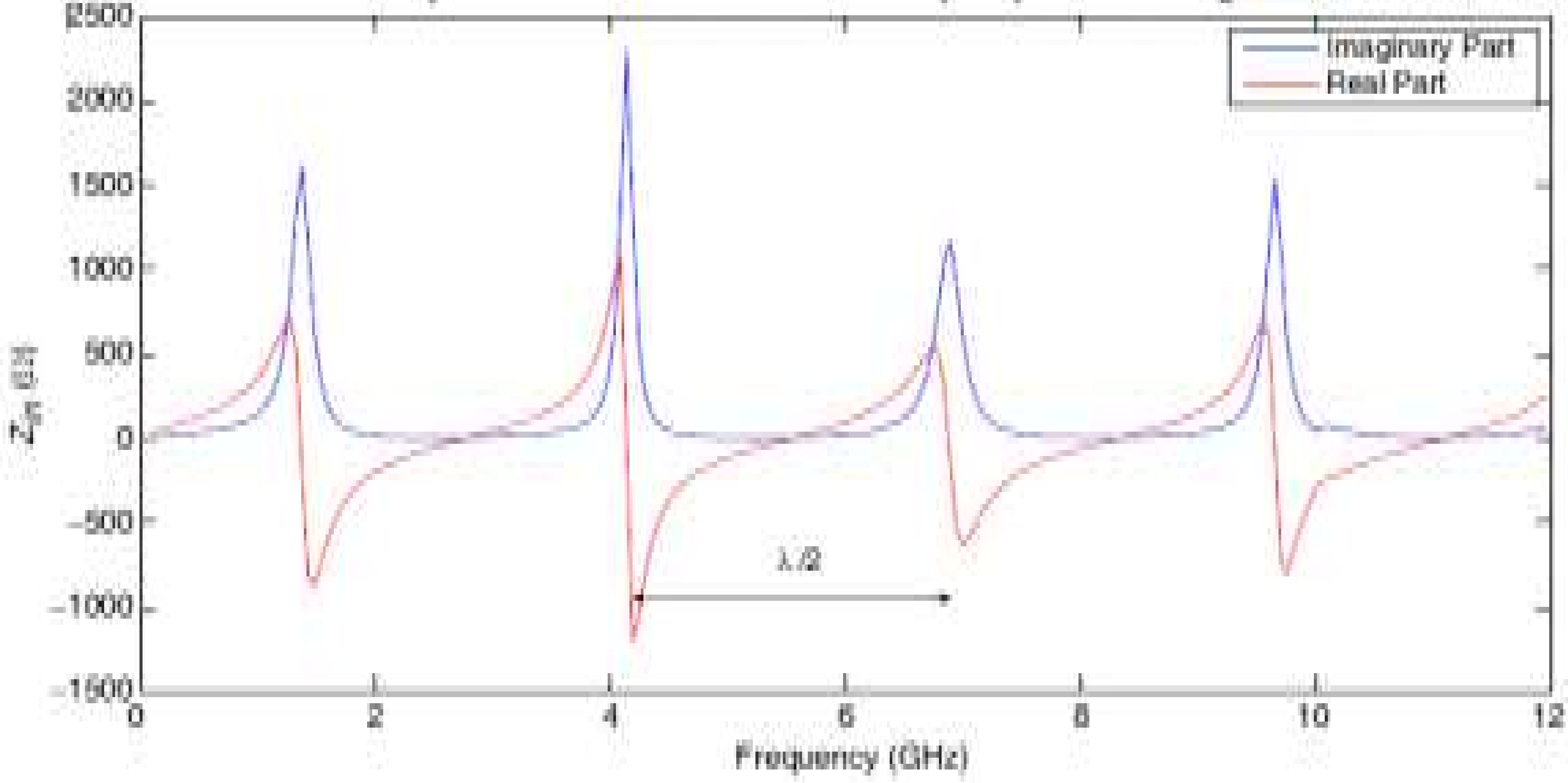
$$\begin{cases} J_{(i,s)} = J_{e,(i,s)} \\ E_{e,(i,s)} = -E_{i,s} + \hat{Z}J \end{cases}$$

?? Boundaries conditions in term current and tension (kirchhoff laws) : global structure

??Based on the modal calculation (Fourier Transform) and the superposition theorem

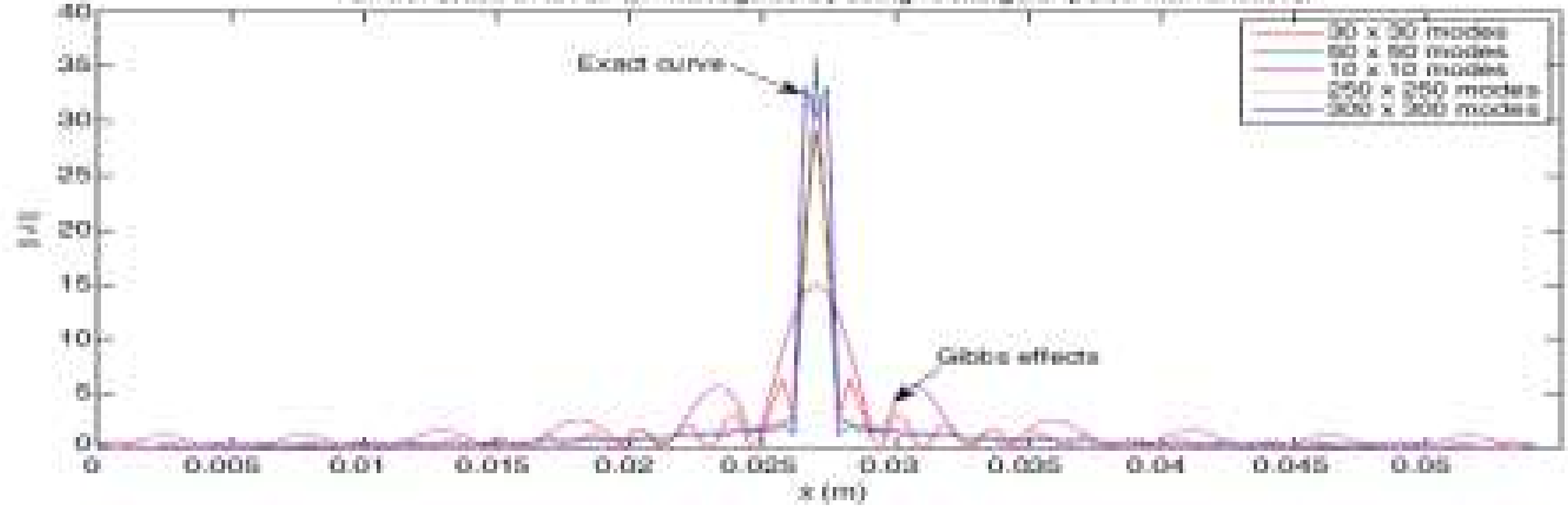
$$[Z_{i,s}] = TF^{-1}[\tilde{z}_{\alpha_p,\beta_q}]TF$$
$$[Y_{i,s}] = TF^{-1}[\tilde{y}_{\alpha_p,\beta_q}]TF$$
$$[S_{i,s}] = TF^{-1}[\tilde{s}_{\alpha_p,\beta_q}]TF$$

Numerical results: applications

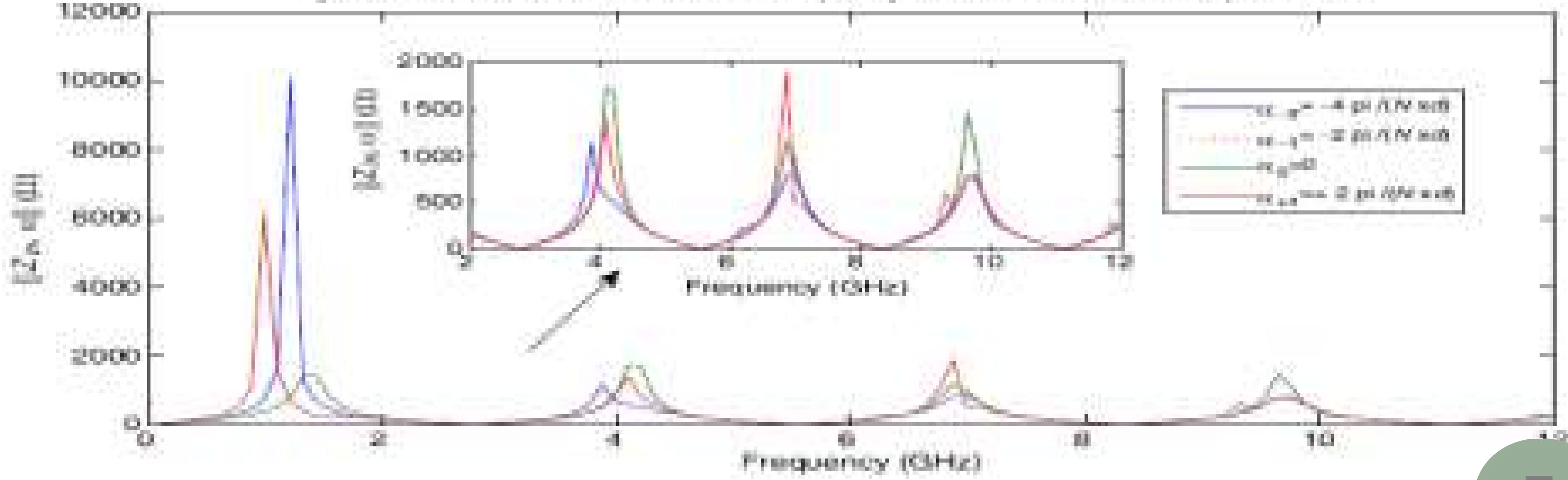


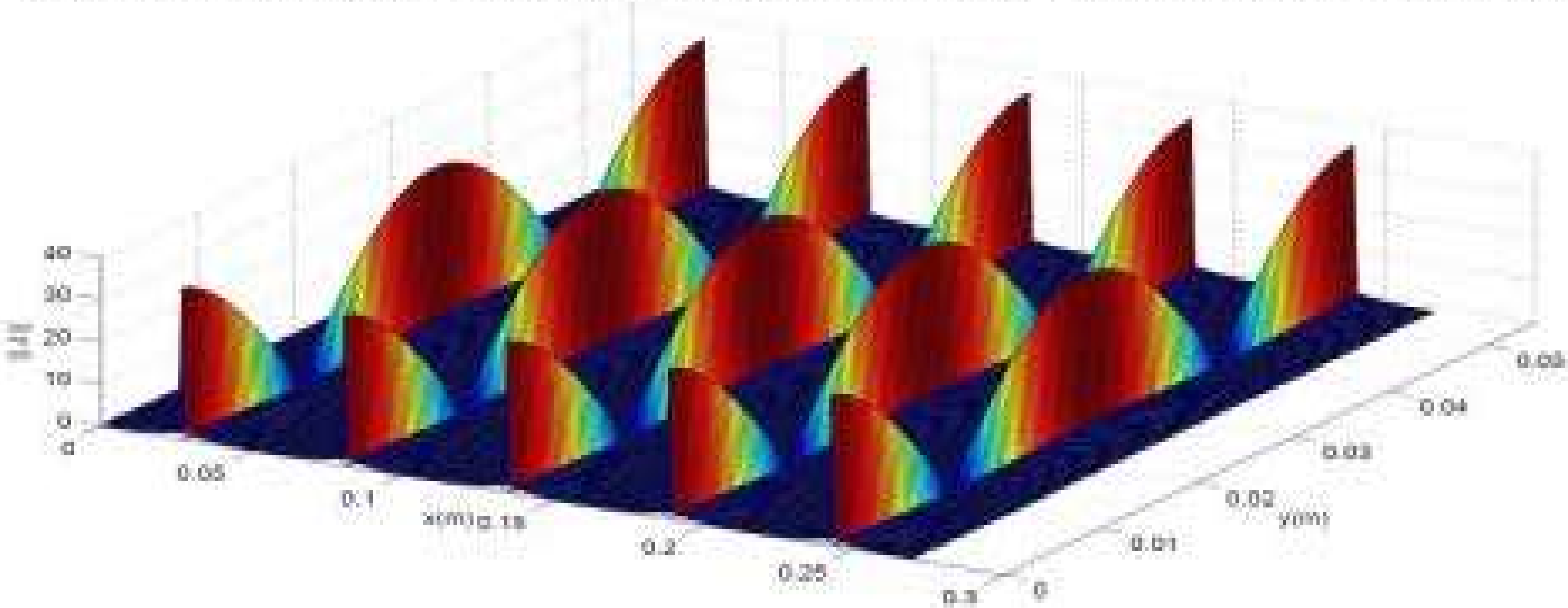
The real and imaginary parts of the input impedance evaluated by the MoM method as a function of frequency at the convergence.

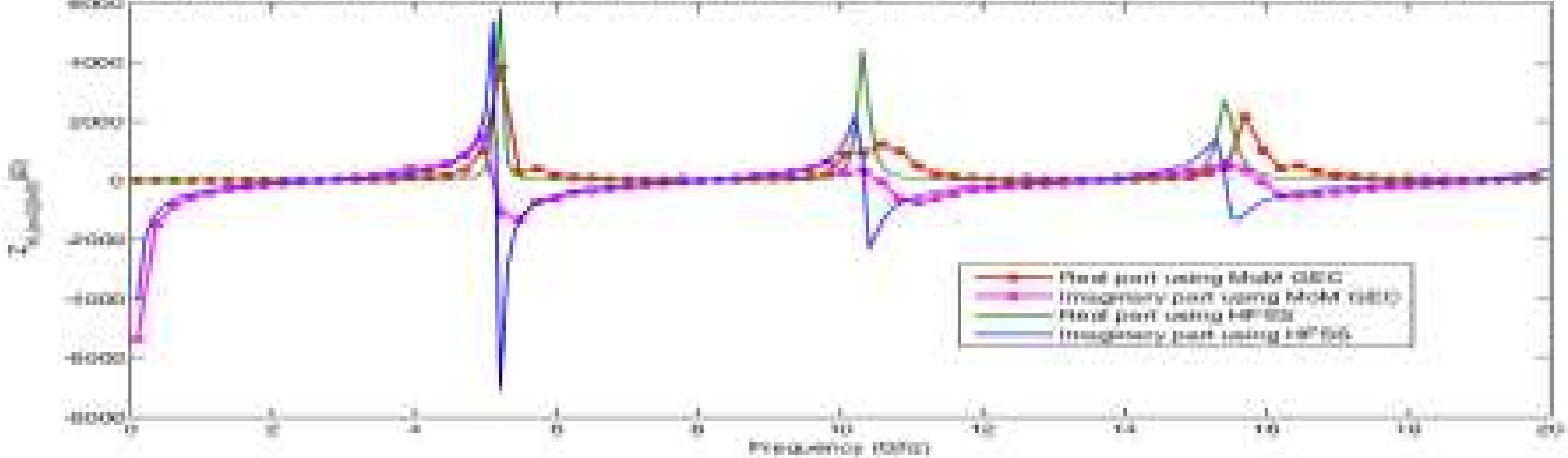
Numerical convergence of the current
distribution evaluated by the MoM-GEC method as a function of modes
number (case of an EPEP waveguide by using rectangular pulse trial function).

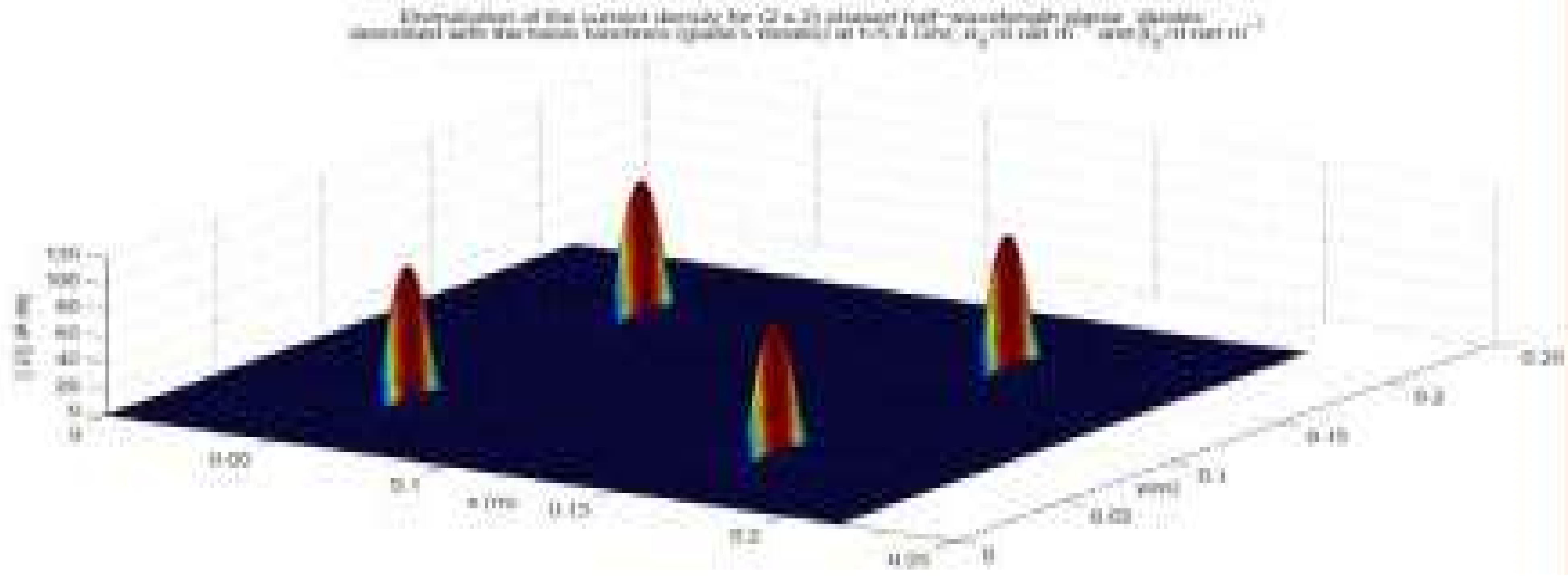


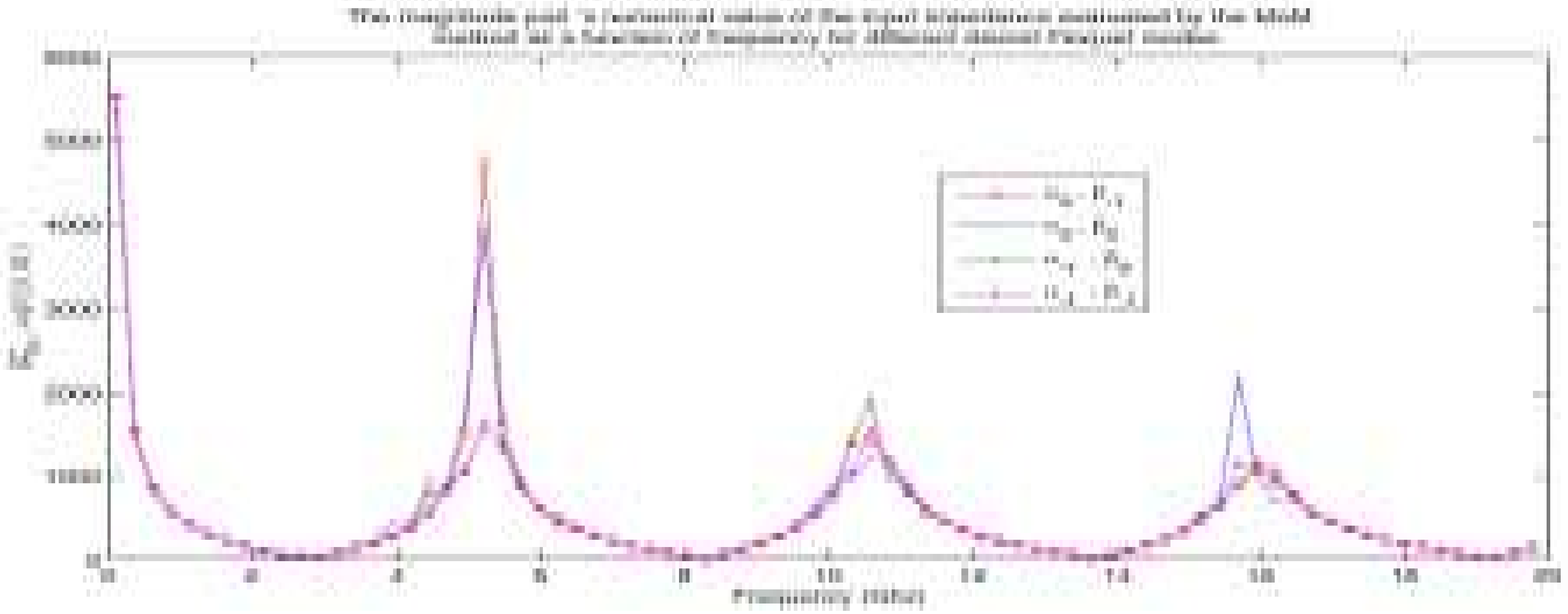
The magnitude part's numerical value of the input impedance evaluated
by the MoM method as a function of frequency for different discrete Floquet modes.

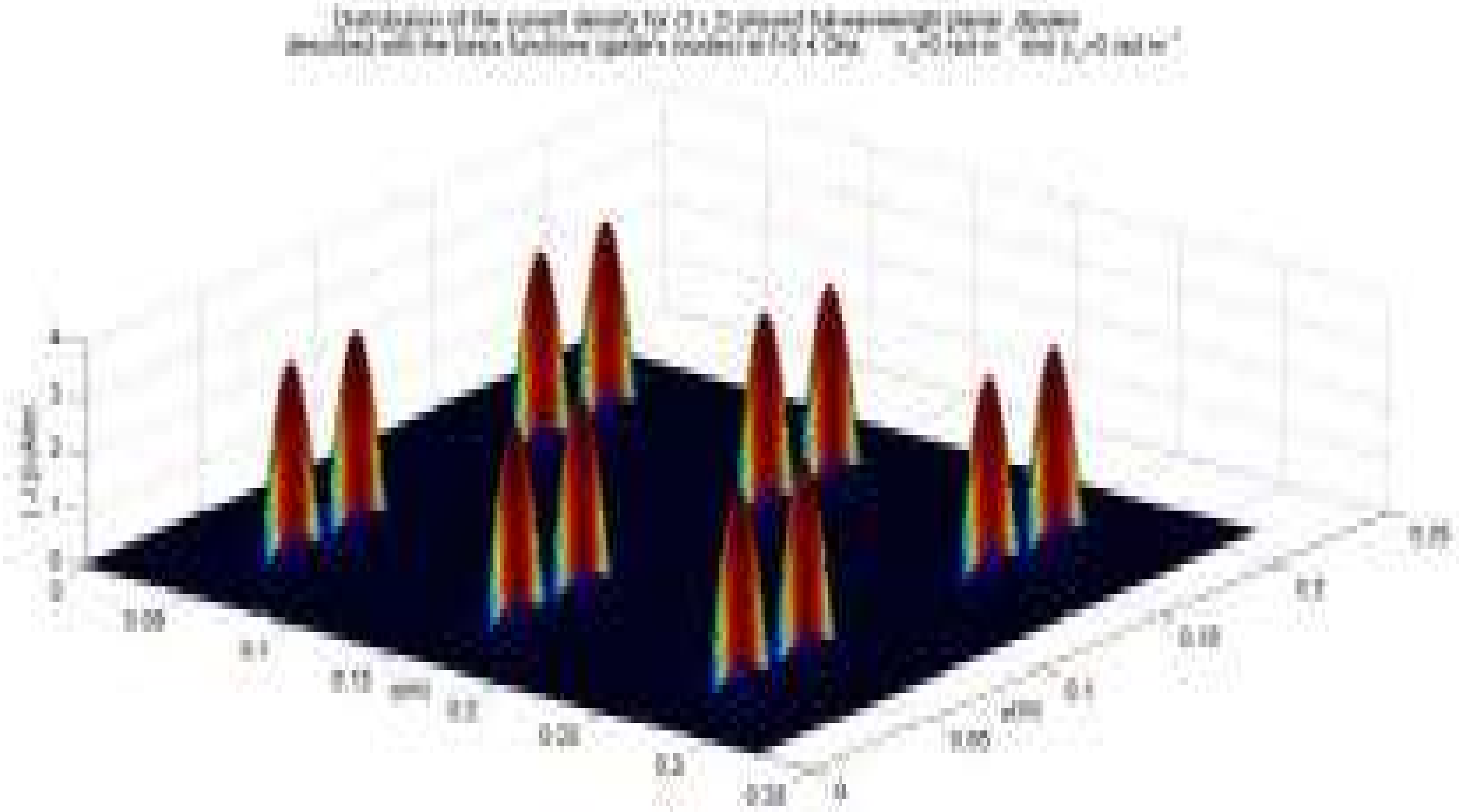



Distribution of the current density for 8 phased micro-strip array described with basis functions (guide modes) at f=5.4 Ghz and α=0 rad m⁻¹

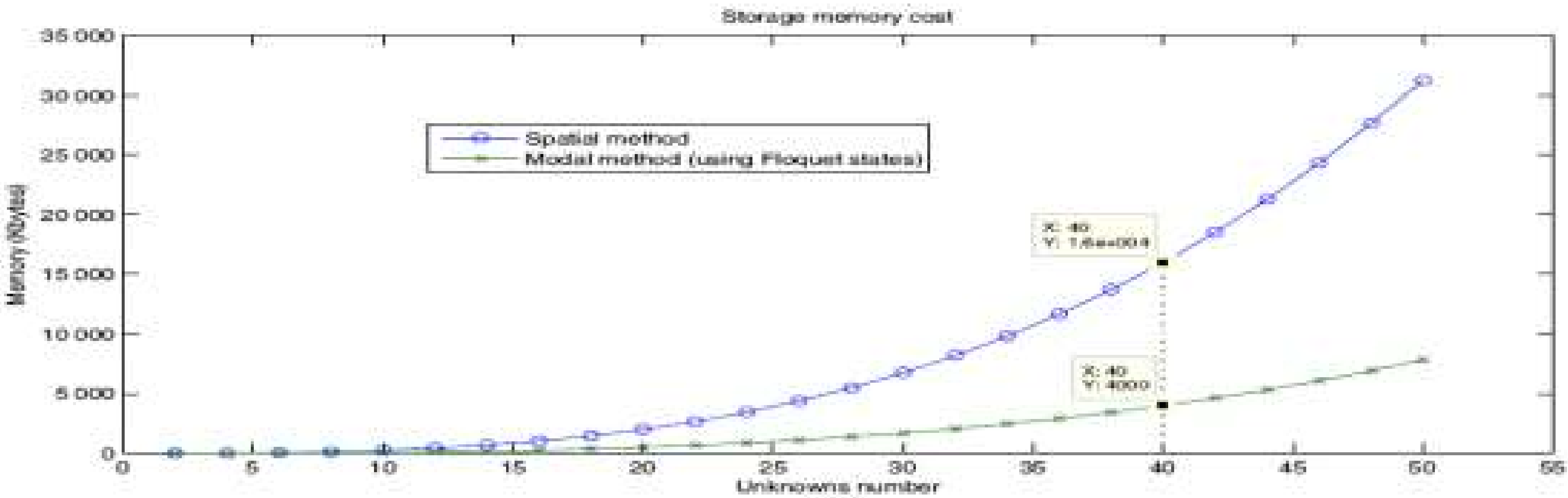

The real and imaginary parts of the input impedance evaluated by the MoM GEC method as a function of frequency at the convergence and compared by those obtained by HFSS (unit cell).


0
20
40
60
80
100
120
0.05
0.1
0.15
0.2
0.25
x (m)
0
0.05
0.1
0.15
0.2
0.25
y (m)

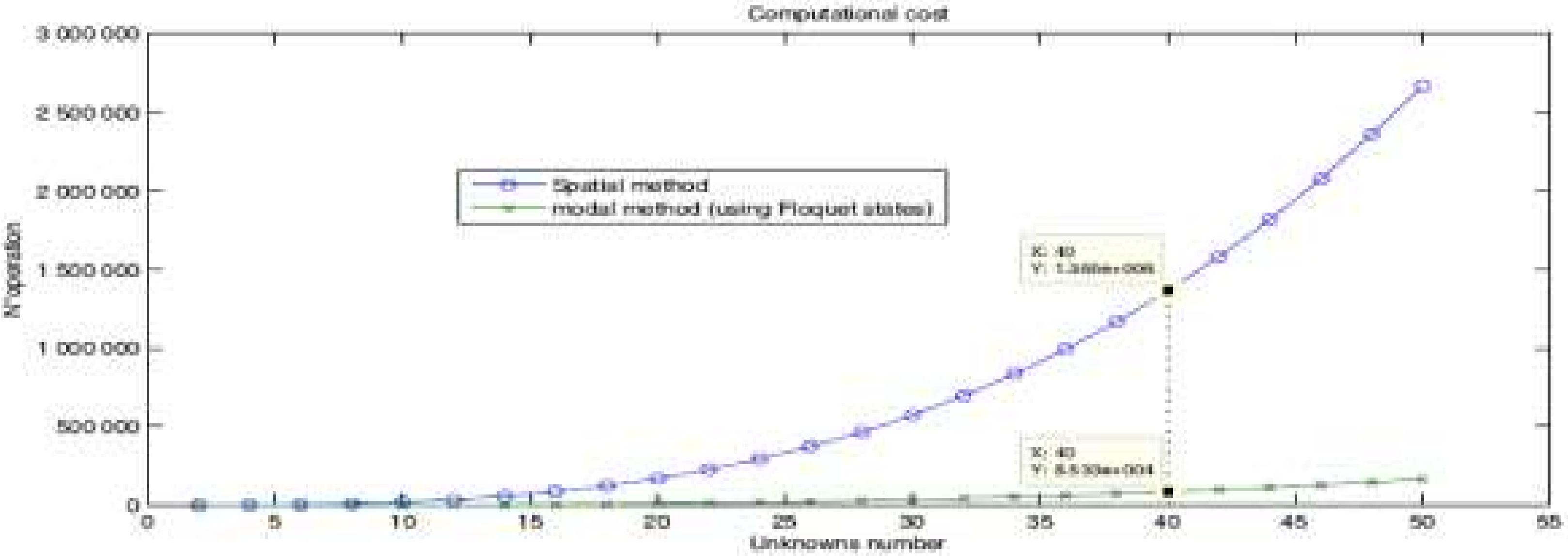

0
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12
14
16
18
20
Frequency (GHz)

Distribution of the current density for (3 x 3) [illegible] planar dipoles
[illegible] with the basis functions [illegible]
J (A/m)
0
1
2
3
4
0
0.05
0.1
0.15
y(m)
0.2
0.25
0.3
0.35
0
0.05
x(m)
0.1
0.15
0.2
0.25

Storage memory and time consuming



(a)



(b)

Conclusion

In this paper, we present a new modal approach for the fast and efficient calculation of mutual coupling in planar periodic structures. It is important to show that the modal decomposition to study and analyze finite and infinite periodic structures successfully removes the complexity of the proposed problem. For example, the employed formalism based on Floquet analysis reduces the electromagnetic calculation on one unit cell, in contrast to old methods to study the wave behavior of the whole structure. This allows an easier computation of the scattering matrix, by using a simple elegant Fourier Transformation. The essential advantage of this new modal analysis is reducing computing time and memory requirement which are roughly proportional to the square or cube of the number of array elements.

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